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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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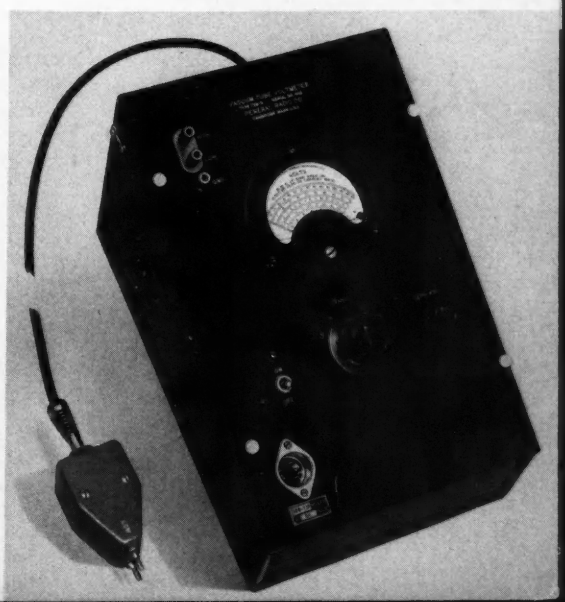
THE TYPE 726-A VACUUM-TUBE VOLTMETER AS A RADIO-FREQUENCY AMMETER

● **AS A VOLTAGE-MEASURING DEVICE** for use in parallel-resonance methods of admittance measurement the vacuum-tube voltmeter has been widely adopted. In this service, because of the low input losses for a given voltage reading[1], the shunting effect of the voltmeter on a high-Q tuned circuit is generally small and high precision in the measurement of small conductances may be attained.

For series-resonance methods of impedance measurement, in which one point of the circuit is grounded, the vacuum-tube voltmeter may be used as a current-measuring device. In this service the voltage drop across a known impedance is used as a measure of the current.

The feature of low input losses is as important in the series-resonance methods as in the parallel-resonance methods, since it is necessary to maintain high-Q tuned circuits for precise measurements of small resistances. It is therefore essential to use, as the

FIGURE 1. Panel view of the TYPE 726-A Vacuum-Tube Voltmeter, showing the probe in which the diode is housed.



[1]At low frequencies, the input conductance of the TYPE 726-A Vacuum-Tube Voltmeter is approximately 0.16 μmho. At high frequencies the input admittance is approximately equal to that of a 6.0 μμf condenser having a 2.5% power factor. For an excellent discussion of the input conductance of a diode rectifier at low frequencies, see C. B. Aiken, "Theory of the Diode Voltmeter," *Proc. I.R.E.*, Vol. 26, No. 7, p. 859, July, 1938.

known impedance, a circuit element which has as nearly pure a reactance as can be obtained.

TYPE 505 Condensers make excellent shunts for use with the TYPE 726-A Vacuum-Tube Voltmeter. For any given capacitance, and at any one frequency, the lower limit of current which can be measured is fixed by the lowest voltage which can be read. The higher limit of current is fixed either by the highest voltage which can be read or by the maximum voltage which the condenser will stand at the particular frequency used. The curves of Figure 3 illustrate, as a function of frequency, the maximum current which can be measured by the TYPE 726-A Vacuum-Tube Voltmeter with four standard TYPE 505 Condensers as shunts. Below 4 Mc the maximum current which can be measured is seen to be limited by the 150 volt maximum reading of the voltmeter. Above 4 Mc the maximum current is limited by losses in the condensers as shown.

FIGURE 3. Plot of maximum current, as a function of frequency, which can be read with the TYPE 726-A Vacuum-Tube Voltmeter and four different TYPE 505 Condenser shunts. The lines with positive slope correspond to a 150-volt reading of the voltmeter. The line with negative slope corresponds to 1 watt loss in the condensers.

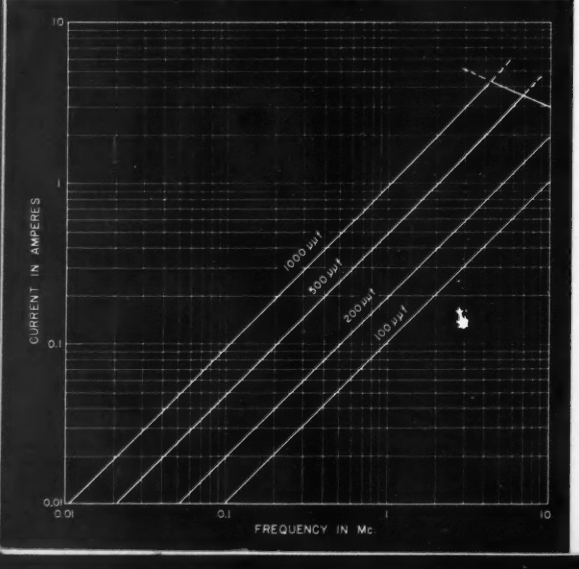


FIGURE 2. TYPE 505 Condenser has plug-in terminals as shown here. In a measuring circuit equipped with jacks, condensers can be easily changed, or stacked in parallel. The voltmeter probe plugs into the jack tops of the condenser terminals.

When the TYPE 726-A Vacuum-Tube Voltmeter is used as an ammeter, the effective series resistance component of the input impedance is the pertinent loss representation. Figure 4 illustrates, as a function of frequency, the effective series resistance of a TYPE 726-A Vacuum-Tube Voltmeter when shunted with four typical TYPE 505 Condensers. By comparison with other types of radio-frequency ammeters, the extremely low losses introduced by the shunted TYPE 726-A Voltmeter are to be emphasized. Using the 1.5 volt range, with a 500 $\mu\mu$f shunt, at a frequency of 1 Mc, the effective series resistance is 0.16Ω and the full-scale current reading is 4.8 ma. The radio-frequency power taken from the circuit is therefore 3.6 microwatts. A well-designed thermocouple for the same current range ordinarily requires a power input of the order of 6 milliwatts for a generated d-c voltage of 10 millivolts open-circuit and consequently has an effective series resistance

of approximately 260 Ω. The advantage to be gained through the use of the voltmeter with high-Q circuits is tremendous at low current levels.

In resonance methods of measurement the absolute value of current is generally not needed for calculations since the equations are expressed in terms of current and voltage ratios. When the voltmeter is used in such circuits it is therefore unnecessary to know the variation of effective capacitance of the shunts with frequency in anything except a general way.

When it is necessary to measure the absolute value of the current, the variation of effective capacitance with frequency must be known. This can be easily computed for any TYPE 505 Condenser by means of the equation

$$C_e = \frac{C}{1 - \omega^2 LC}$$

where C_e is the effective capacitance, C the static capacitance, and L the inductance. For TYPE 505 Condensers mounted in small cases, the inductance is approximately 0.055 μh and, in large cases, 0.085 μh.[2]

Certain limitations and precautions should be noted in connection with the use of the condenser-shunted vacuum-tube voltmeter as an ammeter.

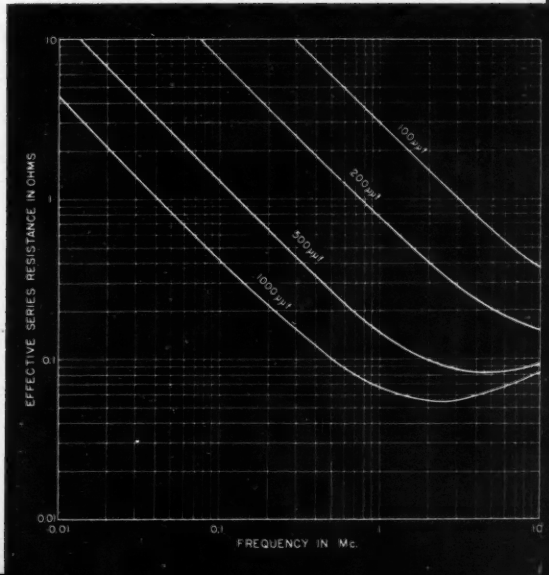
The TYPE 726-A Vacuum-Tube Voltmeter, while calibrated in r-m-s volts, actually responds to peak values. If used to measure distorted current waves, with a condenser shunt, the relation between various harmonic components will be destroyed because of the frequency dependence of the input impedance. The meter-scale reading when multiplied by $\sqrt{2}$ will not, in this case, give correct results for peak values and the instrument should therefore be used to measure only currents of nearly pure waveform, such as are encountered in resonant circuits.

Because of the unbalanced input circuit of the voltmeter, the shunted combination should only be used when one side can be grounded. Otherwise the high capacitance of the low side of the voltmeter circuit to ground will shunt that part of the circuit under test which lies between that point and ground.

In series-resonance circuits, capacitances to ground are usually the most troublesome residual parameters encountered. When it is necessary to measure absolute values of current with the shunted voltmeter, the magnitude of any shunting residual capacitance should be determined and included in the total effective capacitance. Two positions in which the shunted voltmeter may be used with series-resonance circuits are shown in Figure 5.

For applications in which a flat frequency response is required, the TYPE 726-A Vacuum-Tube Voltmeter can be

FIGURE 4. Plot of effective series resistance of TYPE 726-A Vacuum-Tube Voltmeter when used as an ammeter with four different TYPE 505 Condenser shunts.



[2]Curves of power factor and capacitance rise for typical TYPE 505 Condensers are given in the General Radio *Experimenter*, Vol. 12, No. 11, p. 4, April, 1938.

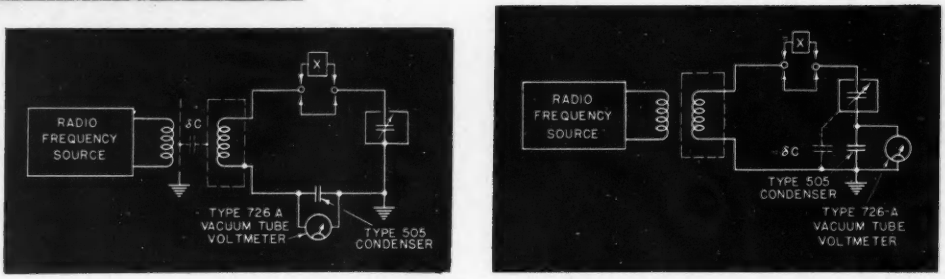


FIGURE 5. Two ways in which the shunted TYPE 726-A Vacuum-Tube Voltmeter can be connected in series-resonant circuits. The residual capacitances shown as δC in the two cases shunt the voltmeter combination and must be included in the effective capacitance.

used with TYPE 500 Resistors for shunts. The power required for full-scale deflection on the low range is considerably greater than that required with TYPE 505 Condensers. For a full-scale deflection on the 1.5-volt scale with a current of 4.8 ma, a resistance of 313Ω is required. The resistance and, consequently, driving power are in this case practically the same as those encountered with a thermocouple. At lower currents less power is required with the resistance-shunted vacuum-tube voltmeter than with a thermocouple, while at higher currents the reverse is true.

Both TYPE 505 Condensers and TYPE 500 Resistors are equipped with terminals which permit stacking up of units in parallel. The TYPE 726-A Vacuum-Tube Voltmeter probe can, therefore, be plugged into the shunt and TYPE 274 Plugs in the shunt used as the composite probe terminals.

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